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Phonological processes across word and language boundaries: Evidence from code-switching

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Abstract
Previous research on the phonetics and phonology of code-switching has largely focused on word internal phenomenon, such as voice onset time. However, many phonological processes occur across word boundaries, and in the case of code-switching, potentially across language boundaries. This study examines the application of phonological rules across word and language boundaries in cases of code-switching, exploiting cross-linguistic differences in voicing assimilation and spirantization processes in English and Spanish. Results from an oral production paradigm conducted with Spanish–English bilinguals showed an asymmetrical impact of code-switching: switched and non-switched tokens differed in Spanish, but not English. A similar pattern was found for bilinguals of different language dominance profiles. This asymmetry is discussed with respect to the different language-specific degrees of variability in production. Moreover, results from the current study suggest that while phonological processes may be anchored to language-specific lexical items or phonemes, the licensing environment is language non-specific.

Keywords: Code-switching; bilingualism; phonology; cross-linguistic; spirantization; assimilation; Spanish

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1. Introduction

Although bilinguals rarely produce unintentional language switches (Poulisse, 1999), they often intentionally shift between languages for a variety of pragmatic (e.g., Auer, 1998) or social functions (e.g., Zentella, 1997). This process, known as code-switching, is broadly defined as the alternation between two or more languages or language varieties in a single discourse (Myers-Scotton, 1993). As previous research has shown that bilinguals effectively establish two sets of unique norms for their two languages, including different phonetic targets (e.g., Flege, 1987) and phonological rules (e.g., Simon, 2010), successfully switching between languages implies shifting between two unique sets of phonetic and phonological norms.

While switching languages at the lexical level involves a categorical change form one language to the other at the point of switch, excepting cases of cognates and borrowings, processes at the phonetic and phonological level may present a more complex framework. Previous research on the phonetics of code-switching has largely focused on the potential effects of phonetic transfer at or near the point of switch. Results from this line of research have generally shown that code-switched tokens may be produced with a degree of phonetic transfer, shifting in the direction of the opposite language (e.g., Antonoiu, Best, Tyler, & Kroos, 2011), although the presence and size of this shift is dependent on both language internal and external factors (e.g., Bullock & Toribio, 2009). The focus of this line of research has been squarely on word internal, and thus language-internal, phonetic and phonological phenomena. Yet, many phonological processes occur *across* word boundaries, and in the case of code-switching, potentially across language boundaries.

Given the previous focus on word-internal phonetic and phonological processes, the current study examines the potential application of phonological processes across word and language boundaries in cases of code-switching. Two experiments were conducted to address this question, comparing switched and non-switched productions in both English and Spanish. Experiment 1, exploiting cross-linguistic differences in /s/ voicing, with voicing in English generally described as progressive and Spanish as regressive, examines the potential for voicing in word-final /s/ immediately preceding the point of switch. Experiment 2 examines the spirantization of word-initial voiced stops in intervocalic position, which are subject to spirantization in Spanish but not in English, immediately following the point of switch. This study adds to our theoretical understanding of bilingual phonetic and phonological production, and adds to ongoing discussion regarding the mechanisms responsible for bilingual language selection. Moreover, such an examination provides unique insight into the nature of phonological rules (i.e., where rules are anchored and how rules are licensed) otherwise unavailable in monolingual populations.

2. Literature Review

2.1. Bilingual Phonological Systems

Previous research on bilingual phonetic and phonological systems has established that bilinguals are able to maintain different inventories or sets of phonetic targets for each of their two languages (e.g., Caramazza, Yeni-Komshian, Zurif, & Carbone, 1973). In some cases, usually for highly proficient and early bilinguals, the norms employed in each of their languages reflect the norms of the larger, monolingual community (Mack, 1989; Macleod & Stoel-Gammon, 2005; Magloire & Green, 1999; Nathan, Anderson & Budsayamongkon, 1987). More frequently, bilinguals' productions are not necessarily identical to those of the monolingual community. While previous research has most often shown that bilingual phonetic productions evidence a degree of convergence towards the opposite language (Caramazza et al., 1973; Flege & Hillenbrand, 1984; Flege & Port, 1981; Major, 1987), a limited number of cases of divergence have also been found (e.g., Flege & Eefting, 1987). The ability to distinguish between two unique sets of phonetic targets has been found for a variety of different 'types' of bilinguals, including both early/simultaneous bilinguals, as well as late second language learners (Flege, 1995). Worth noting, there is ongoing debate regarding the nature of acquisition of multiple phonetic targets. For early or simultaneous bilinguals, both single (Unitary System Model: Volterra & Taeschner, 1978) and emergent dual phonetic stores have been proposed (Dual Systems Model: Keshavarz & Ingram, 2002). For late bilinguals or second language learners, while some have proposed that acquisition takes place on a segment-by segment basis (e.g., Speech Learning Model: Flege, 1995), shaped by the relevant phonetic and phonological contrasts of the L1 (e.g., Perceptual Assimilation Model-L2: Best & Tyler, 2007; Second Language Linguistic Perception: van Leussen & Escudero, 2015), others have suggested that learning may occur at the level of the feature (de Jong, Hao, & Park, 2009). Important for the current study, while these frameworks may differ in their approach to acquisition, they agree in the conclusion that bilinguals are able to acquire and maintain two separate sets of phonetic targets. While bilinguals effectively establish and maintain separate sets of phonetic norms, it is important to note that these systems can interact. Interaction between the two phonetic systems has been observed during the acquisition process (e.g., Keshevarz & Ingram, 2002), during unilingual productions in bilingual mode (e.g., Simonet, 2014), and in cases of code-switching (see below). The language mode continuum refers to the relative activation of each of a bilingual's languages, driven by contextual and psychological factors, with bilingual mode representing a point in which both languages are similarly engaged (Grosjean, 2008). Discussing cross-linguistic phonetic interaction during bilingual language mode and code-switching, Olson (2016a) notes that this impact appears to be phonetic, rather than phonological. That is, productions may show evidence of opposite-language transfer, but are generally produced within the speaker's language-specific ranges.

Although the subject of less research to date, bilinguals have also been shown to maintain different sets of phonological processes in their two languages. For example, Simon (2010) found that highly proficient, late bilinguals employed different phonological rules in Dutch (L1), which employs regressive phonological voicing assimilation across word boundaries, and English (L2), which does not. Paralleling the above findings at the phonetic level, Simon (2010) notes that this difference is not categorical, and although English was produced with less phonological voicing than Dutch, it was not entirely absent as would be expected in monolingual English speakers (for Catalan–English see Cebrian, 2000). Again, as with phonetic targets, the successful implementation of different phonological rules in a bilingual's two languages appears to be modulated by both language-external and language-internal factors. For example, with respect to language-external factors, proficiency plays a moderating role, with learners at an early stage in the acquisition process likely to produce the L2 with significant L1 transfer (Schmidt, 2014). Considering language-internal factors, Schmidt (2014) notes that L1 English learners of L2 Spanish perform better (i.e., more nativelike) on intervocalic voiced stop spirantization than regressive fricative voicing assimilation. This difference is tentatively attributed to greater variability in native (Spanish) speaker assimilation and the allophonic (vs. phonemic) status of the voiced fricative in Spanish.

Taken as a whole, this previous research establishes that bilinguals are capable of establishing separate phonetic norms (i.e., inventories) and separate phonological processes in their two languages, although the degree to which these patterns may reflect monolingual targets is subject to both language-external and language-internal factors. As such, when bilinguals engage in code-switching, they must effectively alternate between their two phonetic and phonological systems.

2.2. Code-switching, Phonetics, and Phonology

As research has begun to address the phonetics of code-switching, the principal focus has been on whether code-switching impacts the production of segmental features, and if so, what is the nature of that impact. This growing body of work has predominantly exploited cross-linguistic differences in voice onset time (VOT) (although for rhotic/lateral see Bullock, Toribio, Davis, & Botero, 2005; for vowels see Muldner et al., 2017). VOT is defined as the temporal difference between the release of a stop consonant and the onset of voicing of the following segment, usually a vowel. Voice onset time is one of the primary factors used to differentiate between voiced and voiceless stops. While VOT is not the sole cue to voicing (e.g., for f0 see Abramson & Lisker, 1985), it has been shown to be an effective measure across bi-partite and tri-partite voicing systems. In bi-partite distinctions, languages are generally classified as having either short- (i.e., VOT: 0–30ms) or long-lag (i.e., VOT: 30–120ms) voiceless stops. For example, in word-initial position, Spanish generally has short-lag voiceless stops and English has long-lag voiceless stops.

Broadly considered, a variety of outcomes have been found for this line of research. A number of studies have found unidirectional transfer, in which code-switched productions of Language A shift towards the norms of Language B (e.g., Antoniou et al., 2011), but evidence of the reverse is not found. Other studies have shown bi-directional transfer, in which code-switched tokens in Language A shift towards Language B, and code-switched tokens in Language B shift towards Language A (e.g., Bullock & Toribio, 2009). Lastly, a limited number of studies have found no evidence of an impact of code-switching on phonetic production (e.g., Grosjean & Miller, 1994).[1]

While at first glance, these findings seem to vary widely, several patterns should be highlighted. First, in cases of unidirectional transfer, the most common finding, the long-lag language always shifted in the direction of the short-lag language, never the other way around (English–Spanish: Balukas & Koops, 2015; Bullock, Toribio, González, & Dalola, 2006; English–Greek: Antoniou et al., 2011). This finding holds for both long-lag dominant speakers and short-lag dominant speakers (e.g., Bullock et al., 2009), across both spontaneous (e.g., Balukas & Koops, 2015) and

[1] Worth noting, the two studies that have found no shift in phonetic production resulting from code-switching employed paradigms that may have led speakers to produce careful, clear, or hyperarticulated tokens. Target tokens in Grosjean and Miller (1994) were cross-linguistic homophones, such as the proper name *Carl*. Targets in Muldner et al. (2017) were part of a repeated carrier phrase. For discussion see Bullock and Toribio (2009).

read speech (e.g., Antoniou et al., 2011), and for insertional (Antoniou et al., 2011; Olson, 2016a) and alternational code-switching (Bullock & Toribio, 2009). Second, when bi-directional transfer was found, it was always found in only a subset of participants (only Spanish-dominant bilinguals in Olson, 2016a; only balanced bilinguals in Bullock & Toribio, 2009). In these cases, the groups that evidenced a significant shift in the short-lag language were those that produced the shortest non-switched VOTs in short-lag language. Other participant groups in the same studies displayed the unidirectional transfer patterns described above. Finally, when bi-directional transfer was found, the mean shift was always smaller for the short-lag language than for the long-lag language (Bullock & Toribio, 2009; González López, 2012; Olson, 2016a). For example, Olson (2016a) found a mean shift of 0–5ms for Spanish code-switched tokens and a shift of 5–19ms for English code-switched tokens. Similarly, through an analysis by individual participant, Schwartz, Balas, and Rojczyk (2015) showed that while most participants produced a shift of short-lag code-switched tokens (i.e., Polish) towards the long-lag language (i.e., English), the effect was significant for only one participant. While participants in Piccinini and Arvaniti (2015) showed the expected shift of long-lag tokens towards short-lag norms at the point of switch, they also showed an unexpected divergence, wherein the short-lag tokens became *shorter* at the point of switch. While these results do not fit the broader pattern above, the authors note that the divergent shift was small (3ms) and the non-switched VOTs were relatively long.

In addition to the clear pattern of transfer at the point of switch (either unidirectional or bi-directional), it should be noted that such shifts appear to be phonetic in nature, rather than phonological. That is, code-switching produces small phonetic shifts within the generally acceptable VOT range of the non-switched language. In no case have studies found that participants systematically implement the phonological categories of the opposite language when producing code-switched tokens (for variability in child code-switching see Khattab, 2009).

A relevant distinction can be made between code-switching and language switching (see Olson, 2013). While code-switching occurs within a larger discourse, language switching refers to cued or triggered switches that may occur absent a larger discursive context (i.e., lab-based paradigms). While language switching paradigms have been fundamental for development of cognitive theories of bilingual language selection at the lexical (e.g., Green, 1998) and phonetic levels (Olson, 2013), they differ from code-switching in that they do not allow for the usual preplanning that occurs in natural speech production (see Griffin & Bock, 2000). Preplanning of code-switching has been shown to play a role in phonetic production, with tokens showing phonetic modulation even prior to the point of switch (e.g., Bullock, et al., 2006; Fricke, Kroll, & Dussias, 2016). While some phonetic results from language switching paradigms have largely paralleled findings from connected speech, with long-lag languages showing evidence of cross-language interference (e.g., Goldrick, Runnqvist, & Costa, 2014), others have differed somewhat from results found in code-switching paradigms. For example, Olson (2013) found that language switching asymmetrically impacted the dominant language. Specifically, while the dominant language evidenced phonetic transfer from the non-dominant language, the non-dominant language showed no significant effects of language switching. Olson (2013) suggests that, in the absence of preplanning, such results may reflect an underlying inhibitory mechanism for language selection at the phonetic level (e.g., Green, 1998).

As a whole, this body of research shows that code-switching has a clear impact on phonetic production. Long-lag languages appear to be particularly susceptible to transfer, with VOT shifting in the direction of the short-lag language. Although the short-lag language is also susceptible to transfer, again shifting in the direction of the opposite language, these effects are consistently smaller in size and found only in populations that produce relatively short non-switched VOTs. Bullock and Toribio (2009) suggest that the difference in the effects of code-switching between long- and short-lag languages may relate to the degree of 'phonetic latitude', with long-lag languages allowing for a greater range of acceptable VOTs and more 'room' for transfer. As such, participants may shift VOT production, but not beyond the natural, non-switched ranges for a given language. These findings are echoed in the phonetic shifts— larger for long-lag languages and smaller for short-lag languages—seen in the production of cognates (Amengual, 2012) and variable speech rate (Magloire & Green, 1999) (for discussion see Olson, 2016a).

2.3. Research Questions

Previous research has established that bilinguals do maintain two different phonological systems and can differentially implement phonological rules in each of their two languages. Within research on code-switching, the focus has been squarely on word-internal, and thus language-internal, phonetic and phonological phenomena. Yet, many phonological processes occur across word boundaries. As such, the current study examines the potential impact of code-switching on phonological rule application across word boundaries. This study serves to enhance our understanding of bilingual phonological processes. Moreover, such an examination provides unique insight into the nature of phonological rules that is otherwise not possible in monolingual speech. The specific research questions are as follows:

RQ 1: Do phonological processes (i.e., voicing assimilation and spirantization) that normally occur across word boundaries, also occur across language boundaries?

RQ 2: Does the position of the target sound relative to the point of switch (i.e., prior to the switch or immediately following the switch) interact with the application of phonological processes across word boundaries?

RQ 3: Does language dominance interact with the application of phonological processes across word and language boundaries?

Although phonological rules have been described as "language specific" (Hayes, 2009), it is worth nothing that phonological processes have two main components: the sound that undergoes the process or change and the environment required to license or permit the change. In the absence of a clear initial hypothesis, it is worth considering several potential outcomes. First, it is possible that a change in language will effectively serve to block the application of a phonological rule. In other words, a phonological process normally applied to a sound in Language A, will apply if and only if the licensing environment is also from Language A. This would provide evidence for a language-specific constraint on the environment that licenses the application of a phonological rule. Second, it is possible that a phonological process normally applied to a sound from Language A, will be applied regardless of the language of the licensing environment (Language A or Language B). This would be considered evidence for a lack of language specification for the licensing environment. Third, it is possible that a phonological rule with a licensing environment from the opposite language may only apply in a unidirectional format (e.g., when the licensing environment *follows* the target sound). Finally, it is possible that a phonological process normally applied to a sound from Language A may also be applied to Language B if the licensing environment is from Language A. Such a case, where a phonological process impacts a sound from the opposite language, may be taken as evidence for transfer at the phonological level.

To address the above research questions, two oral production reading paradigms were conducted. Each of these paradigms addressed one phonological process: /s/ voicing assimilation (Experiment 1) and intervocalic spirantization (Experiment 2).

3. Experiment 1

3.1. Methodology

Broadly, in Experiment 1, Spanish–English bilinguals from across the language dominance continuum produced utterances in English and Spanish with and without code-switches. Exploiting cross-linguistic difference in /s/ voicing in English (progressive) and Spanish (regressive), analysis focused on the measure of percent voiced and compared switched and non-switched tokens.

3.1.1. Participants

Forty-nine participants were recruited from the campus and surrounding community of a large, public, Midwestern University. All participants initially self-identified as Spanish–English bilinguals. For the purposes of recruitment, a Spanish–English bilingual was defined as someone who can "comfortably carry out daily conversations in both languages," regardless of age of acquisition or dominance. Subsequent screening ensured that all participants spoke either English or Spanish (or both) as a native language (i.e., exposure from birth). Subjects reporting significant use of a third language were excluded.[2]

To assess participants' language dominance, a language background questionnaire was administered (Bilingual Language Profile (BLP): Birdsong, Gertken, & Amengual, 2012). The BLP relies on self-reporting of language history, language proficiency, language use, and language attitudes. Self-rating has been shown to correlate with linguistic performance, including both monolingual and bilingual speakers (Flege, Mackay, & Piske, 2002; Flege, Yeni-Komshian, & Liu, 1999; Jia, Aaronson, & Wu, 2002). Following methodology by Birdsong et al. (2012), each participant's response across the four categories of the background questionnaire were

[2] Of the initial pool of potential participants ($N = 54$), two were eliminated as they were native speakers of languages other than English or Spanish. An additional three potential participants were eliminated as they reported a high degree of proficiency in a third language. In this case, a high degree of proficiency was determined as a self-rating of greater than 4, on a Likert scale of 0–6 (0 = not well at all, 6 = very well), in response to the question "how well do you speak X language?" While the goal was to exclude those who were highly proficient, the particular threshold was determined arbitrarily. Subsequent analysis showed that shifting the cutoff (proficiency > 3) to exclude additional participants did not significantly impact the results for either Experiment 1 or Experiment 2.

calculated into a composite dominance score. Each of the four categories was weighted equally. Possible dominance scores range from -180 (highly Spanish-dominant) to +180 (highly English-dominant). A dominance score of 0 indicates that a participant is equally dominant in English and Spanish. Scores in the current study ranged from -124 to 113 (M = 5.1, SD = 67.8). Figure 1 illustrates the distribution of participants along the BLP language dominance continuum. A total of 22 participants fell on the Spanish-dominant side of the continuum, and 27 were on the English-dominant side of the continuum. For further description of participant backgrounds, each participant's L1 and L2 was operationalized using the BLP dominance score, with L1 referring to the more dominant language and L2 to the less dominant language.

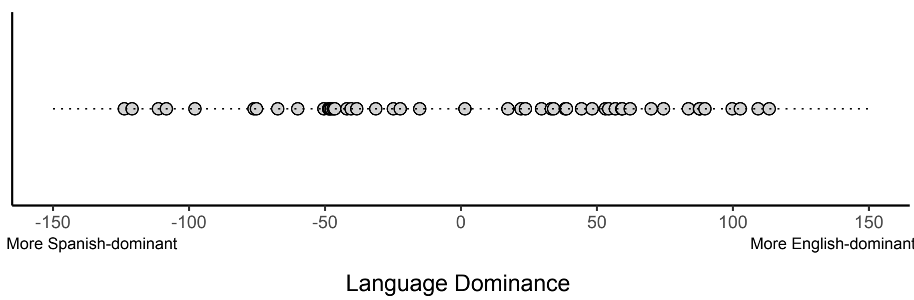

Figure 1. Language dominance by participant.

While they differed in overall levels of dominance, all participants are considered to be highly proficient in both languages, as indicated by self-rating scores on a composite proficiency score (Likert scale 0–6, 0 = not proficient at all, 6 = very proficient) encompassing reading, writing, speaking, and listening skills (L1 proficiency M = 5.86, SD = 0.33; L2 proficiency M = 4.87, SD = 0.78).[3] Relevant for the current task, participants reported a high degree of proficiency for both languages with respect to the proficiency subcomponents of reading (L1 proficiency M = 5.84, SD = 0.47; L2 proficiency M = 5.00, SD = 0.98) and speaking skills (L1 proficiency M = 5.89, SD = 0.31; L2 proficiency M = 4.73, SD = 0.93). In addition, all participants reported using both languages on a daily basis (L1 daily usage percentage M = 69.5, SD =16.6; L2 daily usage percentage M = 30.2, SD = 16.4) and favorable attitudes (via Likertscale 0–6, 0 = highly negative attitude, 6 = highly positive attitude) towards both languages (L1 attitude M = 5.56, SD =0.57; L2 attitude M = 4.62, SD = 1.12).

3.1.2. Phonological Voicing in English and Spanish

With respect to their implementation of phonological rules, and particularly voicing assimilation, English and Spanish show overall contrastive patterns. Both languages contain the phoneme /s/, with voiced and voiceless allophones [s] and [z] respectively. However, the distribution of these allophones differs. English is considered to have progressive assimilation, in which a given segment or phoneme acquires a feature of the preceding segment (Yavas, 2016). Illustrating this pattern in English, the plural marker /s/, is pronounced as either [z] or [s], depending on the voicing feature of the preceding consonant: *beads* [bidz] vs. *beats* [bits]. In this case, the [voice] feature of the phoneme proceeding the plural /s/ is transferred to the fricative. In contrast, Spanish is generally considered to show regressive assimilation, in which a given segment acquires a feature of the following segment (Hualde, 2005). Illustrating this pattern in Spanish is

[3]

the near minimal pair: *rasgo* [razɣo] ‘characteristic/feature’ vs. *rasco* [rasko] ‘I scratch’. Here, the [voice] feature of the /s/ is determined by the following consonant. Important to note, this rule may also apply across word boundaries. Example (1) provides these general rules in phonological notation.

(1) a. English
/s/ → [+voice]/ C __ $
[+voice] $

b. Spanish
/s/ → [+voice]/ __ C $
[+voice] $

Worth considering, while phonological notation suggests a more categorical distinction between [s] and [z] realizations of /s/, voicing assimilation has been shown to be variable in Spanish. For example, Campos-Astorkiza (2015) showed that /s/ + lateral sequences in Spanish were produced as unvoiced (18.5%), partially voiced (49.5%), and fully voiced (31.9%). Similar patterns were shown for /s/ + nasal sequences (unvoiced: 31.7%; partially voiced: 37.9%; fully voiced: 30.4%). As such, voicing in Spanish can be considered a “tendency rather than a mandatory process” (Schmidt & Willis, 2011, p. 2) and full voicing (i.e., 100%) is not expected in any condition.

3.1.3. Stimuli
Exploiting this cross-linguistic difference in phonological voicing, stimuli for the current study consisted of utterances from four different language conditions: (a) English Stay, (b) English Switch, (c) Spanish Stay, and (d) Spanish Switch. The target token always contained the phoneme /s/ in word-final position and was embedded within the middle of the utterance. For code-switched conditions, the target word was always placed immediately prior to the point of switch. For non-switched conditions, tokens were placed in a parallel condition. Examples (2a-d) illustrate these four language conditions. Following the canonical voicing pattern for each language, it is expected that /s/ will be produced as [s] in the English stay condition (2a) and [z] in the Spanish stay condition (2c).

(2) a. *English Stay* &
My friend eat**s n**uts as a healthy snack before he goes to the gym. $
Canonical realization: /s/ → [s] $

b. *English Switch* &
My little sister always eat**s n**aranjas después del colegio. $
‘My little sister always eats oranges after school.’ $

c. *Spanish Stay* &
Por la tarde, escucha**s n**iños jugando en el parque. $
‘In the afternoon, you hear children playing in the park.’ $
Canonical realization: /s/ → [z] $

d. *Spanish Switch*

Tumbado en la cama, escucha**s n**oises outside your house.
'Lying in bed, you hear noises outside your house.'

Target tokens (English $n = 30$, Spanish $n = 30$) consisted of English and Spanish words with the phoneme /s/ in word-final position. It is worth noting that the English and Spanish target word-final /s/ differed somewhat in their immediate phonetic environment, due to language-specific phonotactic constraints. English /s/ was always preceded by a voiceless consonant, to provide a voiceless /s/ on which the Spanish voicing rule could apply. Spanish /s/ was preceded by a vowel (for additional discussion see Section 3.2.1). The word following the target token was always a noun with a word initial, voiced consonant. The following words were balanced for word-initial phonemes /n, m, l/ (for each phoneme: $n = 10$ per language) and were also non-cognate. Each target token was used twice, once in the non-switched condition and once in the switched condition. Similarly, each following word was used twice, once in the non-switched condition and once in the switched condition. The repeated use of each token and following word was intentional, ensuring that the switched and non-switched conditions were highly comparable.

Considering the general preference for code-switching at points where syntactic structure is aligned between both languages (MacSwan, 2013, Pfaff, 1979; Poplack, 1980), all target tokens were verbs and the immediately following token was always a noun or the first word in a noun phrase. To ensure that all code-switches were grammatical, stimuli were evaluated by a panel of three early Spanish–English bilinguals. In the case that one of the three considered the code-switch to be ungrammatical, the utterance was modified and resubmitted to the panel. Likewise, all non-switched stimuli were evaluated for grammaticality by native speakers of the relevant languages. All utterances are considered to be grammatical.

Utterances were balanced for the total number of syllables across both relevant conditions: target language (English vs. Spanish) and utterance type (switched vs. non-switched). Equivalence testing using the two one-sided t-test procedure (Lakens, 2017), with $\alpha = 0.05$ and $\Delta_L = -0.5$ and $\Delta_H = 0.5$, confirmed that the number of syllables was similar across target languages (English $M = 18.3$, $SD = 3.7$; Spanish $M = 18.7$, $SD = 4.2$; equivalence test $t(116) = 2.231$, $p = 0.014$) and utterance types (switch $M = 18.7$, $SD = 3.7$; stay $M = 18.3$, $SD = 4.2$; equivalence test $t(116) = -2.204$, $p = 0.015$). Equivalence bounds were determined using a benchmark strategy and medium effect size (Lakens, Scheel, & Isager, 2018; Cohen, 1988). Moreover, code-switched utterances were balanced for the number of syllables drawn from each language (English $M = 9.2$, $SD = 2.5$; Spanish $M = 9.5$, $SD = 3.4$; equivalence test $t(109) = 2.182$, $p = 0.016$).

In the code-switched utterances, color signaled the language to be used by the participant: Language A was presented in blue or green, while language B was presented in red or orange. The language-color pairing was counterbalanced across participants. Paralleling the color conditions in the code-switched utterances, the non-switched utterances were also presented with a color switch between the target token and the following token. If a participant received the pairing English = red/orange, then non-switched English utterances (as in 1a) were presented in red and orange, with a color switch immediately following the target token. This color pairing system allowed for a consistent presentation of language-color pairings, and parallel usage of color alternation across all four conditions. Stimuli were presented in three language blocks: a monolingual English block, a monolingual Spanish block, and a bilingual block. The bilingual block contained all code-switched stimuli, and as such, participants were equally likely to have to switch from English to Spanish as from Spanish to English. Blocking stimuli by language condition allowed for more consistent participant expectations and likely served to move participants towards different positions on the language mode continuum (e.g., Grosjean, 2008).[4] Stimuli for Experiment 2 served as fillers for Experiment 1.

3.1.4. Procedure

Participants were seated in a sound-attenuated booth and instructions and stimuli were presented visually using SuperLab Pro v 5 (Cedrus Corporation, 2015). Participants were recorded using a head-mounted microphone and Audacity recording software (version 2.2.2.0) with a sampling rate of 44.1kHz. Instructions were presented at the start of each block in the language of the block. For the bilingual block, instructions were presented in code-switched text, balanced for the number of syllables in each language (English: 48%, Spanish 52%). In addition to explaining the color-language pairing, participants were instructed to read sentences aloud “as if you were talking to a good friend who is a speaker of [the target language(s)]”. In the case of (self-identified) speaking errors, participants were instructed to simply start the utterance over again. The experiment was self-paced, and participants were allowed a short break between each block to limit fatigue. Interaction in the lab, proceeding the actual experiment instructions, was conducted in the language of the initial block. For example, if a participant were to first perform the bilingual block, they were addressed in both English and Spanish. Utterances analyzed in Experiment 2 were produced during the same session. The full session lasted approximately 45 minutes. All participants provided informed consent and were compensated for their time. The language background questionnaire was administered online and filled out by the participant prior to the experimental session.

3.1.5. Analysis

For the current study, the temporal boundaries of each word-final /s/ phoneme was marked by hand, with special attention to the high-frequency (i.e., 7-10kHz) aperiodic noise in the spectrogram. After marking the boundaries of the fricative, each token was analyzed for voicing via a gradient measure of “percent voiced.” As there have been several different approaches used to quantify voicing in previous literature (see Eager, 2015), three voicing measures were initially performed: (a) *Percent Voiced- Standard Settings*, (b) *Percent Voiced- Gender Specific Settings*, and (c) *Percent Voiced- Manual Measure*. *Percent Voiced- Standard Settings* was calculated using the *voice report* function (via automated script) in Praat v6.0.42 (Boersma & Weenink, 2018) with standard pitch settings (i.e., f0 minimum = 75Hz, f0 maximum = 500Hz). *Percent Voiced- Gender Specific Settings* was also conducted using the *voice report* function, but employing gender specific pitch settings (Eager, 2015) (male: f0 minimum = 70Hz, f0 maximum = 250Hz; female: f0 minimum = 100Hz, f0 maximum = 300Hz). Finally, *Percent Voiced- Manual Measure* was conducted by visually observing and hand-marking the boundaries of periodic waves visible in the spectrogram of the previously marked fricative. While a one-way

[4] While it is unlikely that participants were ever in a truly monolingual mode (for discussion see Grosjean, 2008) given the nature of the recruitment and task (e.g., Marian & Spivey, 2003), it is assumed that the monolingual blocks foster a language mode that is relatively more monolingual than the bilingual blocks.

ANOVA showed a significant difference between voicing measures ($F(2,14085) = 74.79$, $p < .001$), all measures were highly correlated (see Table 1). Subsequent planned pairwise comparisons with Bonferroni adjustment showed that the gender-specific measure ($M = 18.22$, $SD = 28.05$) was significantly different from both the standard settings ($M = 25.01$, $SD = 29.82$, $p < .001$, $d = -0.235$, 95% CI [-0.292, -0.178]) and manual measurement ($M = 25.05$, $SD = 35.21$, $p < .001$, $d = -0.214$, 95% CI [-0.271, -0.157]). However, there was no significant difference between the standard settings and the manual measurement ($p = 1.000$, $d = -0.001$, 95%CI [-0.058, 0.056]). Given the strong correlation between all three measures, a preference for automated measures, and the similarity between the standard settings and manual measurements, results and statistics are reported only for the *Percent Voiced- Standard Settings* measure (henceforth Percent Voiced).

Table 1. Correlation Matrix for Three Voicing Measures

	Standard Settings	Gender Specific Settings	Manual Measure	*M*	*SD*
Standard Settings	–	0.89***	0.83***	25.01	29.82
Gender Specific Settings		–	0.91***	18.22	28.05
Manual Measure			–	25.05	35.21

*** = correlation significant at .001 level

A total of 5,880 tokens were considered for initial analysis (4 language conditions × 3 following-word phonemes × 10 tokens × 49 participants = 5,880). Of initial importance was to establish that each participant employed different phonological voicing rules in the English and Spanish non-switched conditions. As such, after eliminating errors and pauses (see below for definitions), a t-test (unequal variance) was conducted comparing the percent voiced measure for tokens produced in the English and Spanish non-switched conditions for each participant. Participant failing to produce a significant difference in voicing between the English and Spanish non-switched conditions ($\alpha = .05$) were eliminated from analysis. Three participants failed to meet this criterion. Of the remaining 5,520 tokens, approximately 6% were eliminated for various errors ($n = 336$). The majority were eliminated as the result of: /s/ elision, defined as having no visually identifiable aperiodic noise in the spectrogram ($n = 121$), false starts at the target word ($n = 65$), mispronounced target words ($n = 50$) and stimulus errors ($n = 92$).[5] The finding of /s/ elision is expected, given that some dialects of Spanish routinely elide /s/ (e.g., Hualde, 2005), particularly in syllable final position (for discussion see Lipski, 2011). Finally, given that the voicing rule is unlikely to apply when /s/ is followed by a pause, and code-switching is often preceded by a pause, it was necessary to eliminate any token that included a pause. In this case, a pause was defined as a silence in excess of 100ms between the end of frication of the word-final /s/ and the onset of the following word-initial voiced consonant. Approximately 9% of tokens were eliminated due to the presence of a pause ($n = 488$). The decision to use 100ms as the pause cut-off, based on findings by Hieke, Kowal, and O'Connell (1983) that show that pauses of up to 130ms can be psychologically motivated, is considered to be conservative. As such, only data

[5] Stimulus errors consisted of two utterances, both in the English switch condition, in which the target word did not conform to the appropriate criteria. Other errors included: fillers such as 'um' ($n = 1$), laughter ($n = 1$), missing or skipped utterances ($n = 4$), and pauses in the middle of the target word in excess of 100ms ($n = 2$).

with fluid speech were included in the final analysis. A total of 4,696 tokens were included in the final analysis.

All statistical analyses were conducted in R v3.5.1 (R Core Team, 2013). Mixed effects models were performed with the *lme4* 1.1-7 package (Bates et al., 2014). For all mixed effects models, the significance criterion was set at |t| > 2.0. Subsequent pairwise comparisons were conducted with the *emmeans* 1.3.0 package (Lenth, Singmann, Love, Buerkner, & Herve, 2018).

3.2. Results

Initial statistical analysis was conducted using a linear mixed effects model with percent voiced as the dependent variable and target language (i.e., English, Spanish), token type (i.e., stay, switch) and language dominance (i.e., continuous predictor) as fixed effects. Subject was included as a random effect with both random intercepts and slopes by target language and token type. Initial phoneme (i.e., initial phoneme of the following word: /l, n, m/) was included as a random effect with random intercept and slope by target language. This random effects structure was the maximal structure that permitted model convergence. To justify the inclusion of each of the fixed effects, three subsequent models were conducted, each dropping one of the three fixed effects (i.e., target language, token type, language dominance), but maintaining a similar random effects structure. Results demonstrated that the initial model containing each of the three fixed effects (log likelihood = -20519) produced a better fit that each of the three sub-models: without target language (log likelihood = -20592, $\chi^2(4) = 144.53$, $p < .001$), without token type (log likelihood = -20586, $\chi^2(4) = 132.98$, $p < .001$), and without language dominance (log likelihood = -20526, $\chi^2(4) = 144.53$, $p < .013$). Model fit was assessed using conditional ($R^2 = .620$) and marginal R^2 ($R^2 = .353$).

Results for fixed effects from the initial model (Table 2) demonstrate a significant impact of the target language on percent voiced ($\beta = 39.934$, $t = 13.794$), indicating that participants effectively produced different phonological rules in English and Spanish (for random effects see Appendix A). This is expected, given the initial requirement for participants to effectively differentiate between English and Spanish productions detailed in section 3.1.5. While the lack of a significant effect of token type implies that the English stay and English switch tokens did not significantly differ ($\beta = 1.674$, $t = 1.501$), there was a significant interaction between the target language and token type ($\beta = -11.787$, $t = 10.697$). This interaction suggests that the impact of code-switching was different for English and Spanish tokens. Subsequent pairwise comparisons with Bonferroni adjustment (Table 3) show the nature of this interaction. Namely, while there was no significant difference between English stay and English switch tokens, there were significant differences between all other conditions. Worth noting, the Spanish switch condition most closely patterned after the Spanish stay condition, as evidenced by the effect sizes (Spanish stay – Spanish switch: $d = 0.303$; English stay – Spanish switch: $d = -1.309$) in the pairwise comparisons.

Table 2. Fixed Effects of Linear Mixed Effects Model: Percent Voiced

	Estimate	Std. Error	*t*-Value	Lower 95%	Upper 95%
Intercept (English, Stay)	7.517	1.119	6.715	5.279	9.755
Spanish	39.934	2.895	13.794	34.144	45.724
Switch	1.674	1.115	1.501	-0.556	3.904

Language Dominance	-0.010	0.015	-0.661	-0.041	0.021
Spanish: Switch	-11.968	1.094	-10.942	-14.155	-9.781
Spanish: Language Dominance	-0.105	0.042	-2.488	-0.189	-0.021
Switch: Language Dominance	0.007	0.017	0.425	-0.027	0.041
Spanish: Switch: Language Dominance	0.043	0.017	2.571	0.009	0.076

Table 3. Pairwise Comparison of Percent Voiced by Target Language and Token Type

`	Estimate	SE	*df*	t ratio	*p* value	*Cohen's d*	Lower 95%	Upper 95%
English Stay - Spanish Stay	-39.716	2.948	42.00	-13.470	<.001	-1.575	-1.575	-1.448
English Stay - English Switch	-1.440	0.773	4621.71	-1.863	0.375	-0.110	-0.220	0.001
English Stay - Spanish Switch	-29.370	2.946	41.84	-9.971	<.001	-1.309	-1.430	-1.187
Spanish Stay - English Switch	38.276	2.955	42.39	12.951	<.001	1.492	1.359	1.625
Spanish Stay - Spanish Switch	10.346	0.786	4603.34	13.167	<.001	0.303	0.188	0.417
English Switch - Spanish Switch	-27.929	2.953	42.23	-9.459	<.001	-1.222	-1.349	-1.093

These results suggest that the English tokens with word-final /s/ were produced similarly, regardless of the language of the following word. More specifically, as can be seen in Figure 2, English word-final /s/ was produced with minimal voicing (i.e., [s]). As such, the English word-final /s/ appears to consistently follow the English phonological voicing rule. In contrast, the Spanish tokens with word-final /s/ were produced with a greater percentage of voicing than the English tokens. There was a difference between Spanish switch and non-switched tokens, with switch tokens shifting in the direction of English-like norms.

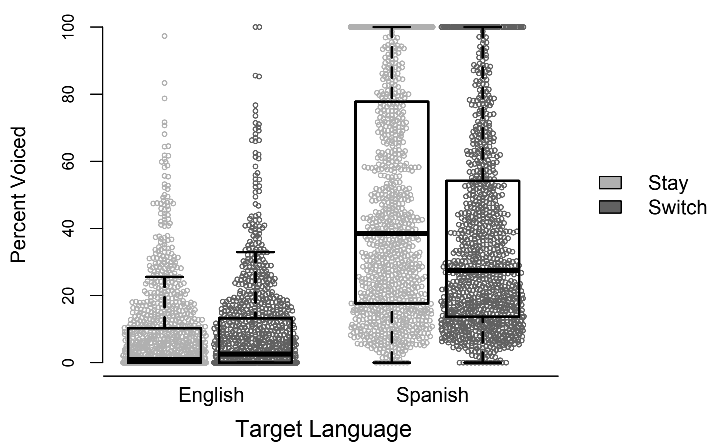

Figure 2. Percent voiced by target language (English, Spanish) and token type (stay, switch).

Finally, there was significant three-way interaction between target language, token type, and language dominance, suggesting that the difference in switch and stay tokens between the two languages was dependent on a participant's dominance. Figure 3 illustrates the percent voiced by target language and token type across the language dominance continuum. While language dominance was considered as a continuous factor, for visualization purposes, Figure 3 divides participants into three different dominance groups. Groupings were produced using an arbitrary dominance score cut-off to allow a roughly equal number of participants in each group: English-dominant (n = 16, dom. score > 40), balanced bilingual (n = 13, -40 < dom. score < 40), and Spanish-dominant (n = 17, dom. score < -40). An analysis of Figure 3 suggests that this three-way interaction may be due to the fact that the more Spanish-dominant participants produced greater voicing of Spanish tokens, both switch and stay, than the English-dominant and balanced bilingual participants.

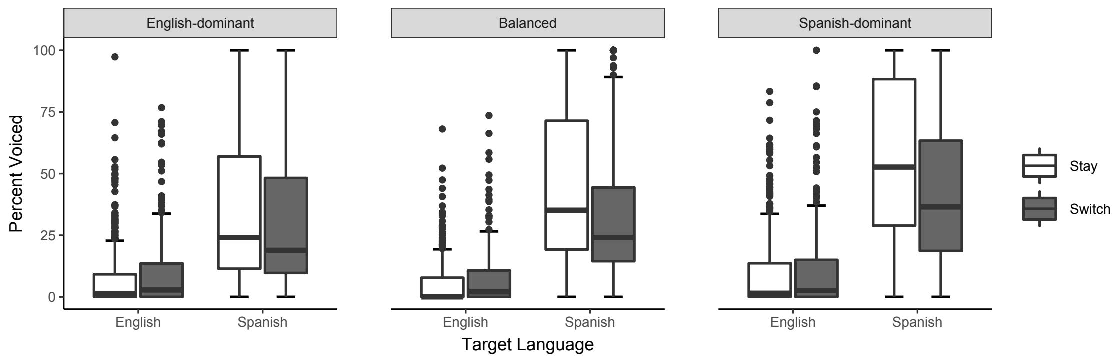

Figure 3. Percent voiced by Language Dominance.

Overall, these results show a similar voicing pattern for participants from across the language dominance continuum. Broadly, there was no difference between switched and non-switched English tokens. That is, word-final /s/ in English tokens was produced with minimal voicing, regardless of the following language. Voicing for word-final /s/ in Spanish tokens was always greater than that of the English tokens. In addition there was a difference between switched and non-switched Spanish tokens, with the switched tokens shifting in the direction of the English language norms.

3.2.1. Accounting for Coarticulation

As noted, English and Spanish target word-final /s/ differed with respect to their immediate phonetic environment, owing to language-specific phonotactics. Again, the English /s/ was always preceded by a voiceless consonant, to provide a voiceless fricative on which the Spanish voicing rule could apply, while the Spanish /s/ was preceded by a vowel. This difference in immediate phonetic environment may have allowed for a differential impact of coarticulation between languages. Broadly defined, coarticulation occurs when a given segment varies to become more like adjacent sounds. In contrast to phonological rules, phonetic coarticulation impacts only a portion (at the segment boundaries) of the target segment (see Keating, 1990; Kühnert & Nolan, 1999). In short, while the English /s/ was bounded by only one voiced phoneme (from the following word), the Spanish /s/ was bounded by, and potentially influenced by, two voiced phonemes. As such, this difference may result in an artificially inflated the gradient percent voiced measure for the Spanish tokens, particularly in the case of otherwise voiceless phonemes. To confirm that the initial findings are not the result of co-articulatory effects, it is worth briefly considering a categorical approach to voicing. Following analysis by Campos-Astorkiza (2015), who found that in /s/ + C[-voice] sequences may be produced up to 33% voiced, this analysis takes 33% voicing as a conservative cut-off point below which voicing *may* be considered the result of co-articulation. Tokens above this threshold are considered to evidence phonological voicing, rather than phonetic coarticulation.

Figure 4 illustrates the percentage of tokens produced above the 33% voicing threshold, plotting the percentage of tokens above the threshold per participant and condition. For completeness, all three initial forms of measurement are illustrated. Comparing the categorical approach (Figure 4) with the gradient approach (Figure 2), a similar pattern emerges. Specifically, relatively few English tokens with word-final /s/ are produced with voicing that is not attributable to co-articulation (for standard settings: English stay *M* =5.2, *SD* = 9.3; English switch *M* = 6.4, *SD* =10.3). A greater number of Spanish tokens with word-final /s/ surpassed the 33% voicing threshold, although again this pattern was somewhat stronger for the non-switched tokens (for standard settings: Spanish stay *M* = 55.5, *SD* = 32.7) than the switched tokens (Spanish switch *M* = 42.2, *SD* = 30.7). Moreover, this pattern was found across all three voicing measurements. Taken as a whole, the patterns found for voicing in the absence of co-articulatory effects suggest that the findings in the initial analysis are not the result of co-articulation.

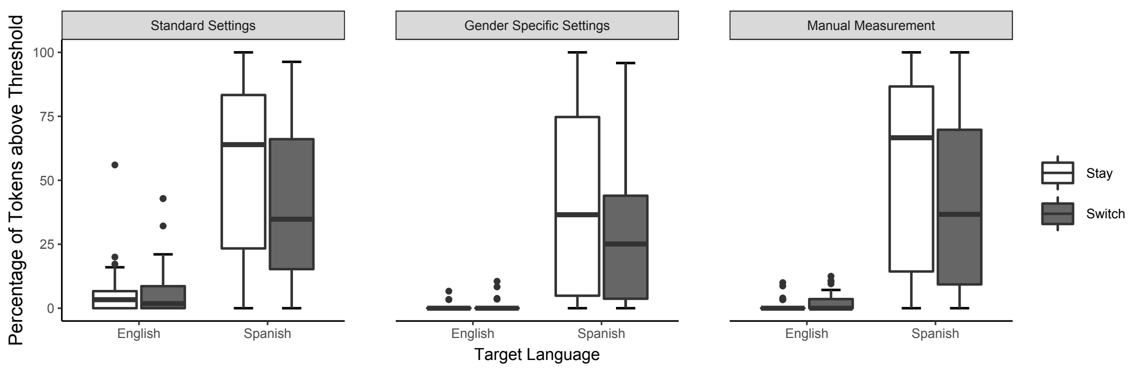

Figure 4. Percentage of tokens by participant surpassing the voicing threshold of 33%, by target language and token type. Separate plots represent the three measurement approaches (i.e., Standard, Gender Specific, Manual).

4. Experiment 2

4.1. Methodology

Experiment 2 focused on the potential effect of code-switching on intervocalic spirantization. Differing from Experiment 1, the process of intervocalic spirantization of voiced stop consonants is examined word-initially, and thus the switched target tokens occurred immediately after the point of switch.

4.1.1. Participants

Participants from Experiment 1 also participated in Experiment 2.

4.1.2. Intervocalic Spirantization in English and Spanish

English and Spanish differ with respect to intervocalic spirantization of voiced stop consonants. English contains only one allophone [b, d, g] for each of the voiced phonemes /b, d, g/. These allophones are produced with significant oral closure and occur in all positions. Spanish, in contrast, employs both stop [b, d, g] and approximant [β, ð, ɣ] realizations of the voiced phonemes /b, d, g/. While the stop allophones occur following a pause, nasal consonant, or lateral (for /d/ only), these phonemes undergo spirantization in intervocalic position, resulting in the approximant realization (e.g., Hualde, 2005; for discussion of L1 English – L2 Spanish acquisition, see Zampini, 1994).[6] It should be noted that the degree of spirantization is subject to language-internal factors, with differences found by prosodic stress (e.g., Shea & Curtin, 2011 among many), place of articulation (e.g., Colantoni & Marianescu, 2010), and surrounding vowel environments (e.g., Cole, Hualde, & Iskarous, 1999).The approximant realization occurs intervocalically, even in word-initial position (Cole, Hualde, & Iskarous, 1999). The key distinction between English and Spanish for the current study, is that in word-initial, intervocalic position, /b, d, g/ are generally produced as occlusives [b, d, g] in English and approximants [β, ð, ɣ] in Spanish.

Acoustically, the stop and approximant realizations can be distinguished by the relative intensity (dB) produced during the closure. Stop consonants, involving a full blockage in the oral cavity, are produced with lower relative intensity than approximants (see Section 4.1.4 below).

4.1.3. Stimuli

Stimuli were drawn from the same four conditions as in Experiment 1: (a) English Stay, (b) English Switch, (c) Spanish Stay, and (d) Spanish Switch. The target token, always contained a word-initial voiced occlusive /b, d, g/. Differing from stimuli in Experiment 1, given that the phoneme of interest occurs in the word-initial position, the target word always occurred immediately *following* the point of switch in the code-switched conditions. For non-switched conditions, tokens were placed in a parallel condition. The examples in (3a-d) illustrate these four language conditions. Following the traditional descriptions of English and Spanish phonology, the /g/ in the English non-switched condition (3a) is produced as an occlusive [g], while the /g/ in the Spanish non-switched condition (3c) is realized as an approximate [ɣ].

(3) a. *English Stay* &
The refugees fl**e g**uns and violence in their home countries. $
Canonical realization: /g/ → [g] $

b. *English Switch* &
*Un amigo mío siempre llev**a** ***g**uns in his truck. $
'A friend of mine always carries guns in his truck' $

c. *Spanish Stay* &
*Un público modern exig**e g**uerras sin muertos civiles.* &
'A modern public demands wars without civilian deaths.' $
Canonical realization: /g/ → [ɣ] $

d. *Spanish Switch* &
Millions of people fle***e g**uerras y probreza para una vida mejor*. $
'Millions of people flee wars and poverty for a better life.' $

---

[6] Traditional descriptions of Spanish phonology have variously referred to the approximant realizations as "fricatives", "slit fricatives", and "approximants" (e.g., Hammond, 2001; Hualde, 2005). Acoustic data suggest that [β, ð, ɣ] are more likely to be produced as approximants than true fricatives (Martínez Celdrán, 2013; Romero, 1996).

Target tokens (English $n = 30$, Spanish $n = 30$) consisted of English and Spanish words with the voiced occlusive /b, d, g/ ($n = 10$ tokens for each occlusive per language) in word initial position. As in Experiment 1, all words were non-cognate. The target word was always a noun or noun phrase. The preceding word was always a verb. The preceding word always ended in a vowel (or semi-vowel in the case of English). As in Experiment 1, to ensure that the switched and non-switch conditions were highly comparable, each target token and preceding word were used twice, once in the non-switch condition and once in the switch condition. All stimuli were judged to be grammatical. The color-language pairing was the same as in Experiment 1.

As in Experiment 1, equivalence testing using the two one-sided t-test procedure confirmed that the number of syllables was similar across target languages (English $M = 18.0$, $SD = 3.9$; Spanish $M = 18.1$, $SD = 3.3$; equivalence test $t(116) = 2.612$, $p = 0.005$) and utterance types (switched $M = 18.3$, $SD = 3.3$; stay $M = 17.9$, $SD = 3.8$; equivalence test $t(116) = -2.202$, $p = 0.015$). Likewise, code-switched utterances were balanced for the number of syllables drawn from each language (English $M = 9.1$, $SD = 2.6$; Spanish $M = 9.2$, $SD = 2.7$, $t(109) = 2.182$, $p = 0.016$).

4.1.4. Analysis
To measure the degree of spirantization, a Consonant-Vowel ratio (CV ratio) was computed for each token. Following previous research (e.g., Hualde, Simonet, & Nadeu, 2011; Ortega-Llebaria, 2004), the CV ratio was calculated by dividing the minimum intensity value (dB) within the temporal bounds of the consonant by the maximum intensity value occurring in the following vowel. As such, a higher value corresponds to a more open, and thus more spirantized, approximant-like production of the stop consonant. The temporal boundaries of the consonant and vowel were marked by hand, with particular reference to the waveform. In several cases, the following vowel was not isolatable from the following consonant (e.g., the rhotic in "bear"). In these cases, the boundary was marked at the end of the consonant (e.g., /R/).

A total of 5,880 tokens were considered for initial analysis (4 language conditions × 3 word-initial phonemes × 10 tokens × 49 participants = 5,880). As in Experiment 1, it was necessary to establish that all participants effectively differentiated between the expected phonological processes in English and Spanish. Again, after eliminating all errors and pauses (see below), a t-test with unequal variance was conducted for each participant on the CV ratio for tokens produced in the English stay and Spanish stay conditions. Participants failing to differentiate between the two languages ($\alpha = .05$) were eliminated from subsequent analysis. Eight participants were eliminated from the spirantization analysis. Of the remaining 4,920 tokens, approximately 3% were eliminated for various errors ($n = 136$): false start at the target word ($n = 67$), mispronounced target word ($n = 57$), or other ($n = 12$)[7]. Lastly, as in Experiment 1, all utterances with a pause at the point of switch were eliminated. As stop consonants may naturally contain a period of silence (during closure), the consonant duration measure formed the basis for pause definition. A pause was defined as any consonant duration (parallel to closure duration) in excess of 1 standard deviation above the group average (329ms). This pause definition was chosen as it is considered to be conservative, ensuring that only connected speech samples were

[7] Other tokens eliminated included fillers ($n = 4$), missing data ($n = 7$), and non-speech noise ($n = 1$).

included in the final analysis. In addition, this definition resulted in a similar percentage of tokens being eliminated from analysis as in Experiment 1. Approximately 8% of tokens were eliminated due to the presence of a pause (n = 398). A total of 4,386 tokens were included in the final analysis of spirantization. Statistical analysis paralleled that of Experiment 1.

4.2. Results

Initial statistical analysis was done with linear mixed effects model with CV ratio as the dependent variable and token language (i.e., English, Spanish), token type (i.e., stay, switch), and language dominance (i.e., continuous) as fixed effects. Subject was included as a random effect with random intercepts and slopes by target language and token type. Initial phoneme (i.e., /b, d, g/) was included as a random effect with random intercept and slope by target language. Again, this was the maximal effect structure that permitted model convergence. To justify the inclusion of each of the fixed effects, three subsequent models were conducted, each dropping one of the three fixed effects (i.e., target language, token type, language dominance), but with an identical random effects structure. Results demonstrated that the model with all three fixed effects (log likelihood = 3590.6) produced a better fit that each of the three sub-models: without target language (log likelihood = 3199.6, $\chi^2(4)$ = 782.04, p < .001), without token type (log likelihood = 3178.1, $\chi^2(4)$ = 825, p < .001), and without language dominance (log likelihood = 3506, $\chi^2(4)$ = 167.44, p < .001). Model fit was assessed using conditional (R^2 = .510) and marginal R^2 (R^2 = .287).

Results for fixed effects from the initial model (Table 4, Figure 5) show a significant impact of target language on the CV ratio (β = .1837, t = 11.471), with participants producing greater spirantization (i.e., a higher CV ratio) in Spanish than English (for random effects see Appendix B). Although token type was also significant (β = .0154, t = 2.113), there was a significant interaction between target language and token type (β = .1504, t = -23.638). This interaction suggests that the impact of code-switching was different for English tokens and Spanish tokens. Parallel to Experiment 1, subsequent pairwise comparisons with Bonferroni adjustment show that while there was no significant difference between stay and switch tokens in English, there was a significant difference between stay and switch tokens in Spanish (Table 5). Specifically, Spanish tokens became more English-like in the switched condition, with a lower CV ratio. In addition, it should be noted that, in contrast to findings for voicing assimilation, the Spanish tokens patterned more closely after the English stay tokens than the Spanish stay tokens, as confirmed by the pairwise comparisons (Spanish stay – Spanish switch, p < .001; English stay – Spanish switch, p = .367). This finding, and the difference between Experiment 1 and Experiment 2, is discussed in section 5.1.2.

Table 4. Fixed Effects of Linear Mixed Effects Model: CV Ratio

	Estimate	Std. Error	t-Value	Lower 95%	Upper 95%
Intercept (English, Stay)	0.5865	0.0133	44.038	0.5599	0.6131
Spanish	0.1837	0.0160	11.481	0.1517	0.2157
Switch	0.0154	0.0073	2.113	0.0008	0.0300
Language Dominance	0.0001	0.0002	0.059	-0.0002	0.0004
Spanish: Switch	-0.1504	0.0064	-23.638	-0.1631	-0.1377
Spanish: Language Dominance	-0.0005	0.0001	-4.095	-0.0008	-0.0003
Switch: Language Dominance	-0.0003	0.0001	-2.733	-0.0006	-0.0001

Spanish: Switch: Language Dominance	0.0013	0.0001	12.670	0.0011	0.0015

Table 5. Pairwise Comparison of CV ratio by Target Language and Token Type

`	Estimate	SE	*df*	t ratio	*p* value	*Cohen's d*	Lower 95%	Upper 95%
English Stay - Spanish Stay	-0.1892	0.0159	3.11	-11.869	0.007	-1.490	-1.622	-1.356
English Stay - English Switch	-0.0188	0.0072	59.42	-2.614	0.070	-0.172	-0.289	-0.054
English Stay - Spanish Switch	-0.0439	0.0171	4.09	-2.564	0.367	-0.360	-0.479	-0.242
Spanish Stay - English Switch	0.1704	0.0168	3.77	10.164	0.004	1.362	1.229	1.494
Spanish Stay - Spanish Switch	0.1454	0.0072	59.12	20.188	<.001	1.093	0.964	1.221
English Switch - Spanish Switch	-0.0250	0.0160	3.13	-1.567	1.000	-0.205	-0.325	-0.085

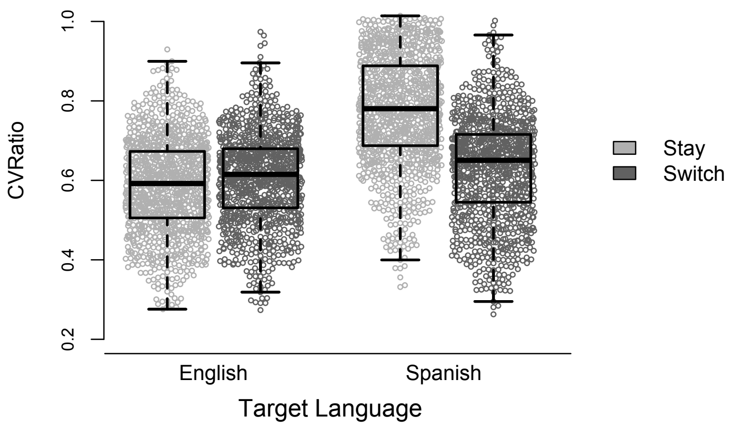

Figure 5. CV Ratio by target language (English, Spanish) and token type (stay, switch). A greater CV ratio corresponds to a greater degree spirantization.

Lastly, there was significant three-way interaction between target language, token type, and language dominance, suggesting that the difference in switch and stay tokens between the two languages was dependent on a participant's dominance. Figure 6 illustrates the CV ratio by target language and token type across the language dominance continuum. Again, although the mixed effects model included language dominance as a continuous predictor, participants were divided into three groups to enhance visualization of the data. For Experiment 2, the groups were constituted as follows: English-dominant (*n* = 10, dom. score > 40), Balanced Bilingual (*n* = 14, -40 < dom. score < 40), and Spanish-dominant (*n* = 17, dom. score < -40). An analysis of Figure 6 suggests that this three-way interaction may be due to the fact that the more Spanish-dominant participants produced a greater degree of spirantization of Spanish tokens, both switch and stay. However, it should be noted that a similar pattern for CV ratio by condition was found for participants across the language dominance spectrum.

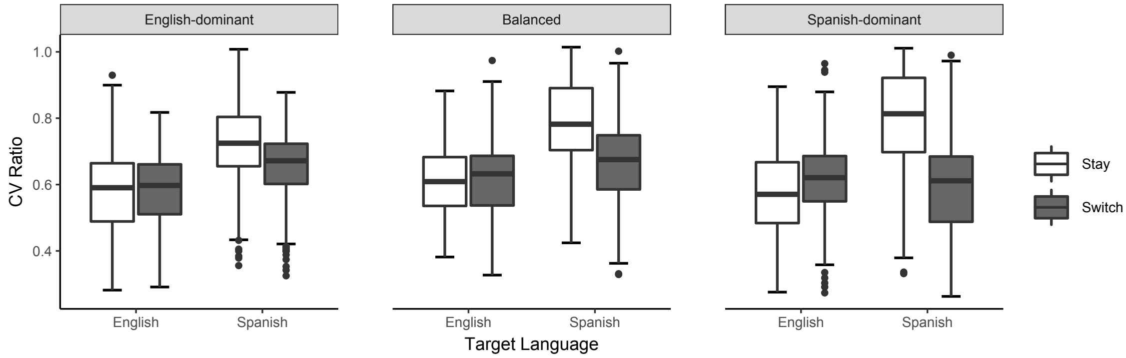

Figure 6. CV Ratio by Language Dominance. A greater CV ratio corresponds to a greater degree spirantization.

As a whole, results from Experiment 2 show that code-switching did not impact the CV ratio for English tokens, with switched and non-switched tokens being produced similarly. In contrast, code-switching did impact the CV ratios for Spanish tokens, with Spanish code-switched tokens being produced with significantly less spirantization (i.e., lower CV ratio) than their non-switch counterparts. This same general pattern was found for bilinguals from across the language dominance continuum. In short, while English tokens remained stable, code-switching caused Spanish tokens to be produced in a more English-like manner.

5. Discussion

5.1.1. Code-switching and Phonological Rule Application

First, results from the current study showed that Spanish-English bilinguals generally distinguish between the phonological processes in their two languages. Moreover, those participants failing to distinguish between the two languages in at least one of the phonological rules were largely drawn from the relative endpoints of the language dominance continuum (Experiment 1 *M* absolute dominance value = 85.5, *SD* =25.4; Experiment 2 *M* absolute dominance value = 78.9, *SD* = 46.9), implying that those who are more balanced in their dominance are more likely to differentiate between the phonological systems of their two languages. This finding adds to the literature showing that bilinguals not only are able to establish different phonetic targets for their two languages, but they are able to apply different phonological rules as well.

With respect to Research Question 1, the current study demonstrates that code-switching impacts phonological rule application across word boundaries. Specifically, this result was found to be asymmetrical, with no impact of code-switching on English tokens—that is, no difference between switched and non-switched tokens in English—found for either voicing assimilation or intervocalic spirantization. In contrast, there was a significant impact of code-switching on Spanish tokens, with differences found between Spanish switch and non-switch tokens. Namely, Spanish switched tokens were more “English-like”, with less voicing assimilation and less spirantization, than non-switched tokens. This asymmetrical impact of code-switching is reminiscent of the previous findings regarding the impact of code-switching at the phonetic level (i.e., VOT). At the phonetic level, the most common finding was a degree of unidirectional transfer, in which code-switched tokens from long-lag VOT languages were produced with significantly shorter voice onset time. This finding has been found for multiple language pairings (for Spanish-English see Bullock & Toribio, 2009; for Greek-English see Antoniou et al., 2011), in spontaneous (e.g., Balukas & Koops, 2015) and read speech (e.g., Olson, 2016a), and for speakers dominant in both long- and short-lag languages (e.g., Bullock et al., 2009). In the case of bidirectional transfer, which appears as a secondary pattern, the magnitude of the shifts found in each of the languages was asymmetrical, with larger shifts found for the long-lag language and smaller shifts in the short-lag language (e.g., Olson, 2016a). Bullock and Toribio (2009) posit that this difference is driven by language-specific ranges in VOT, with long-lag languages allowing a greater range of acceptable VOTs, and thus more "room" for a shift in the VOT of code-switched tokens (for further discussion, see Olson, 2016).

In the current study, code-switching impacted production in Spanish, but not English. Considering the production of the voiced stops, as illustrated above, English employs a single allophone (e.g., [b]), where Spanish presents two allophones (e.g., [b] and [β]). Hualde et al. (2011) note that while spirantized variants of voiced stops are found in casual speech across many languages, including English (e.g., Shockey, 2003), this process is "fully conventionalized" in Spanish for intervocalic environments (p. 304). Moreover, they note that while full occlusion in Spanish would be found only in anomalous or very careful speech, the degree of spirantization is "very variable" (p. 304). As such, it can be assumed that the range of acceptable CV ratios (i.e., spirantization) is greater in Spanish than English. This greater range in Spanish allows phonetic "space" for variability and shift. Similar analysis can be applied to the voicing assimilation condition, where /s/ voicing in Spanish has been found to be an inherently variable phenomenon, with both the application of the phonological rule and the degree to which a particular token is voiced showing a considerable degree of variation (Campos-Astorkiza 2015; Schmidt & Willis, 2010). In English, on the other hand, the current environment allows less variability, with the non-switched condition requiring the voiceless allophone [s], and little variability in voicing beyond co-articulatory processes. As such, there is a larger range of acceptable productions for non-switched tokens in Spanish than in English. This difference in acceptable range is further illustrated by the difference in the percent voiced standard deviations found in the non-switched tokens (English $SD = 12.7$: ; Spanish $SD = 33.4$). As such, the current findings suggest that, much-like word-internal phonetic processes, phonological rule application across word and language boundaries in code-switching may be incur cross-linguistic transfer, but that the degree of transfer is constrained by language-specific factors (i.e., ranges).

Considering the role of language dominance, and responding to Research Question 3, the same pattern of results was found for participants from across the language dominance continuum. While the overall pattern was the same, language dominance influenced the magnitude of the effects, even in non-switched conditions. Participants towards the more English-dominant end of the language dominance continuum produced the most "English-like" productions (i.e., less voicing and spirantization), while the more Spanish-dominant participants produced the most "Spanish-like" productions (i.e., greater voicing and spirantization). This finding is not unexpected, given previous results at the phonetic level (e.g., Olson, 2016a among others), in which the Spanish-dominant groups produced the most Spanish-like voice onset times. Taken as a whole, these findings suggest that, while there are some low-level differences owing to language dominance, the general finding of cross-linguistic transfer at the point of switch, constrained by language-specific factors, holds for all groups of highly proficient bilinguals.

5.1.2. Code-switching and Hyperarticulation

One particular finding presented here warrants additional attention—while Spanish tokens were impacted by code-switching, this effect was not identical for the voicing and spirantization conditions. There was a greater difference between the switch and stay tokens in the spirantization condition than the voicing condition, as illustrated by the different effect sizes in the two conditions (voicing Spanish stay – switch, $d = 0.303$; spirantization Spanish stay – switch: $d = 1.093$). Visual analysis of Figures 2 and 5 highlights this difference. While there are inherent differences in voicing and spirantization, one key difference here, related directly to Research Question 2, is the position of the target tokens relative to the point of switch. In the voicing condition, target tokens occurred immediately prior to the point of switch. In the spirantization condition, target tokens occur immediately following the point of switch.

Seeking to explain the impact of code-switching on prosody, in which code-switched tokens have been shown to be produced with increased pitch range and duration (Olson, 2012, 2016b; for mixed results see Aly, 2017), Olson (2016b) suggested that code-switch tokens (i.e., those immediately following the point of switch) may be produced with a degree of hyperarticulation (for Hyper- and Hypo-articulation Theory see Lindblom, 1990). This notion relies on the inverse relationship between predictability and prosodic prominence (e.g., Smooth Signal Redundancy Hypothesis, Aylett & Turk, 2004; Turk, 2010), in which less predictable tokens are produced with greater duration, pitch, and "care of articulation" (e.g., Bell, Brenier, Gregory, Girand, Jurafsky, 2002). Olson (2016b) argues that code-switches may be considered to be relatively less predictable than non-switched tokens. Moreover, Olson (2016b) found that code-switches in an otherwise monolingual discourse evidence greater hyperarticulation (i.e., greater pitch range and longer duration) than code-switches in a bilingual discourse (see also Aly, 2017), suggesting that the predictability of a code-switch is variable and driven by the larger discourse context.

In the current study, a hyperarticulation of code-switched tokens could potentially explain the difference between findings in the two experiments. While hyperarticulation of prosodic features may involve an expansion of pitch height and duration, hyperarticulation of voiced stops would likely include a greater degree of occlusion. For example, Hualde et al. (2011) note that Spanish voiced stop consonants may be produced with a greater degree of occlusion during very careful (i.e., hyperarticulated) speech. As a decrease in local predictability and a corresponding increase in cognitive load may be associated with code-switching, this effect would be stronger following the point of switch (as in Experiment 2) than prior to the point of switch (Experiment 1).[8] Overall, this difference between findings in Experiments 1 and 2 may provide further support for the notion of the hyperarticulation of code-switched speech, and highlights the complex

[8] Although this study was not designed to systematically assess the potential for hyperarticulation, this proposal finds tacit support in an initial analysis of consonant duration. In the spirantization condition, the voiced stop consonants were longer in the code-switched (M = 120ms, SD = 55ms) than the non-switched (M = 96ms, SD = 50ms) condition (*diff.* = 24ms) While the same pattern held for the fricative in the voicing assimilation condition, the magnitude of the difference was much smaller (switch: M = 99ms, SD = 33ms; stay: M = 94ms, SD = 35ms, *diff* = 4ms). The differing degrees of expansion suggest greater hyperarticulation in the spirantization condition (post-switch) than the voicing assimilation condition (pre-switch).

interactions between code-switching, cognitive factors like predictability, and phonetic production.

5.1.3. Phonological Rules: Anchoring and Licensing
As a number of authors have noted, research on the code-switching practices of bilinguals can provide a unique tool to analyze linguistic features that would be otherwise unavailable in monolingual speech. In the current study, the analysis of phonological rule application across word and language boundaries serves to enhance our understanding of the underlying nature and specificity of phonological rules. In his description of phonological rules, Hayes (2009), states that phonological rules are "language specific." But, a phonological rule or process has two relevant components: the sound that undergoes the change and the environment that licenses such a change. In the case of phonological processes at the word boundary, the environment that licenses such a sound change may occur in a different word than the sound that undergoes the change. In code-switching, the licensing environment may consist of lexical items from opposite language.

Results from the current study suggest that phonological processes may be anchored to language specific lexical items or phonemes, but the licensing environment may not be language specific. Broadly, the phonological processes in question – voicing assimilation and intervocalic spirantization – were applied only to tokens from the target language (i.e., Spanish). While Spanish tokens were produced in accordance with the Spanish-specific phonological rules, English tokens (switched or non-switched) were not produced according to these Spanish-specific phonological rules. This finding suggests that the phonological rule is intrinsically linked to the language of the lexical item (and phoneme) that undergoes the phonological change. In contrast to the language-specific nature of the phonological rule anchor, the environment that licenses a phonological rule appears to be non-language specific. Spanish tokens were produced in accordance to the Spanish-specific phonological rules, regardless of whether the licensing environment was from a Spanish (i.e., non-switched) or English (i.e., switched) lexical item. For example, Spanish tokens with word final /s/ were produced with a significant degree of voicing when the following consonant was [+voice], regardless of the language from which the following consonant was drawn. Thus, drawing on the findings presented here, it is possible to posit that while phonological processes are language-specific, or anchored to language-specific lexical items or phonemes, the environment that licenses such processes are not language specific.

6. Conclusion
Previous research on the phonetics and phonology of code-switching has largely focused on word-internal processes, but a number of phonological processes occur across word boundaries. Seeking to address this gap, the current study examined the potential for cross-linguistic influence in phonological rule application across word and language boundaries in code-switched speech. The results speak to both the processes involved in code-switching, as well as the underlying nature of phonological rules. Results were asymmetrical, with Spanish code-switched tokens evidencing a degree of cross-linguistic transfer, while English tokens showed no impact of code-switching. This result was found for tokens immediately prior to the point of switch (i.e., /s/ voicing assimilation) and immediately after the point of switch (i.e., intervocalic spirantization), and for participants from across the language dominance continuum. These

results, parallel to previous findings at the phonetic level, imply a degree of cross-linguistic transfer, but with such transfer constrained by language-specific norms or ranges and subject to larger discursive processes (i.e., predictability-driven hyperarticulation). Moreover, considering the underlying nature of phonological processes, these results suggest that while a phonological rule may be anchored to language-specific lexical items or segments, the environment that licenses the application of the phonological rule is language non-specific.

While the current study represents an initial approach to code-switching and cross-boundary phonological processes, future research should seek to challenge and confirm these results across a variety of phonological processes and language pairings. Moreover, given the difference seen at the phonetic level between language switching and code-switching, further work may consider the difference between the outcomes of phonological rule application at the surface and the underlying mechanisms governing language selection.

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References

Abramson, A. S., & Lisker, L. (1985). Relative power of cues: F0 shift versus voice timing. In V. Fromkin (Ed.), *Phonetic linguistics: Essays in honor of Peter Ladefoged* (pp. 25–33). Orlando, FL: Academic Press.

Aly, A. M. (2017). *Prosodic effects of code-switching in Spanish-Basque bilinguals* (Unpublished doctoral dissertation). University of California Los Angeles, Los Angeles, CA.

Amengual, M. (2012). Interlingual influence in bilingual speech: Cognate status effect in a continuum of bilingualism. *Bilingualism: Language and Cognition 15*(3)*,* 517–530. https://doi.org/10.1017/S1366728911000460

Antoniou, M., Best, C., Tyler, M., & Kroos, C. (2011). Inter-language interference in VOT production by L2-dominant bilinguals: Asymmetries in phonetic code switching. *Journal of Phonetics, 39*(4), 558–570. https://doi.org/10.1016/j.wocn.2011.03.001

Auer, P. (1998). The pragmatics of code switching: A sequential approach. In L. Milroy & P. Muysken (Eds.), *One speaker, two languages, cross-disciplinary perspectives* (pp. 115–135). Cambridge, UK: Cambridge University Press.

Aylett, M., & Turk, A., (2004). The Smooth Signal Redundancy Hypothesis: A functional explanation for relationships between redundancy, prosodic prominence, and duration in spontaneous speech. *Language and Speech, 47(*1), 31–56. https://doi.org/10.1177/00238309040470010201

Balukas, C., & Koops, C. (2015). Spanish-English bilingual voice onset time in spontaneous code-switching. *International Journal of Bilingualism*, 19(4), 423–443. https://doi.org/10.1177/1367006913516035

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-7 http://CRAN.R-project. org/package1⁄4lme4.

Barr, D., Levy, R., Scheepers, C., & Tily, H. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*, 255–278. https://doi.org/10.1016/j.jml.2012.11.001

Bell, A., Brenier, J., Gregory, M., Girand, C., & Jurafsky, D. (2002). Predictability effects on durations of content and function words in conversational English. *Journal of Memory and Language*, *60*(1), 92–111. https://doi.org/10.1016/j.jml.2008.06.003

Best, C, & Tyler, M. (2007). Nonnative and second-language speech perception: Commonalities and complementarities. In M. Munro & O.S. Bohn (Eds.), *Second language speech learning: The role of language experience in speech perception and production* (pp. 13–34). Amsterdam: John Benjamins.

Birdsong, D., Gertken, L. M., & Amengual, M. (2012). Bilingual language profile: An easy-to-use instrument to assess bilingualism. COERLL, University of Texas at Austin. Retrieved from https://sites.la.utexas.edu/bilingual/

Boersma, P., & Weenink, D. (2018). Praat: doing phonetics by computer. Version 5.1.07. [computer program]. Available from http://www.praat.org/

Bullock, B., & Toribio, A. J. (2009). Trying to hit a moving target: On the sociophonetics of code-switching. In L. Isurin, D. Winford, & K. de Bot (Eds.), *Multidisciplinary approaches to code-switching* (pp. 189–206). Philadelphia, PA: John Benjamins.

Bullock, B., Toribio, A. J., Davis, K. A., and Botero, C. G. (2005). *Phonetic convergence in bilingual Puerto Rican Spanish.* In B. Schmeiser, V. Chand, A. Kelleher, & A. Rodriguez (Eds.), Proceedings of the 23rd West Coast Conference on Formal Linguistics (pp. 101–113). Somerville, MA: Cascadilla Press.

Bullock, B., Toribio, A. J., González, V., & Dalola, A. (2006). Language dominance and performance outcomes in bilingual pronunciation. In M. Grantham O'Brien, C. Shea, & J. Archibald (Eds.) *Proceedings of the 8th generative approaches to second language acquisition conference* (pp. 9–16). Somerville, MA: Cascadilla Proceedings Project.

Campos-Astorkiza, R. (2015). Segmental and prosodic conditionings on gradient voicing assimilation in Spanish. In R. Klassen, J. M. Liceras, & E. Valenzuela (Eds.), *Hispanic linguistics at the crossroads: Theoretical linguistics, language acquisition and language contact. Proceedings of the Hispanic Linguistics Symposium 2013* (pp. 127–144). Amsterdam: John Benjamins.

Caramazza, A., Yeni-Komshian, G.. Zurif, E. B. & Carbone, E. (1973). The acquisition of a new phonological contrast: The case of stop consonants in French-English bilinguals. *Journal of the Acoustical Society of America* 54(2)*,* 421–428. https://doi.org/10.1121/1.1913594

Cebrian, Juli. (2000). Transferability and productivity of L1 rules in Catalan-English interlanguage. *Studies in Second Language Acquisition, 22*(1)*,* 1–26.

Cedrus Corporation. (2015). SuperLab Pro (version 5.0.5) [Computer program]. San Pedro, CA.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, N.J: L. Erlbaum Associates.

Colantoni, L., & Marinescu, I. (2010). The scope of stop weakening in Argentine Spanish. In M. Ortega-Llebaria (Ed.), *Selected Proceedings of the 4th Conference on Laboratory Approaches to Spanish Phonology* (pp. 100–114). Somerville, MA: Cascadilla Proceedings Project.

Cole, J., Hualde, J. I., & Iskarous, K. (1999). Effects of prosodoic and segmental context on /g/-lenition in Spanish. In O. Fujimura, B. D. Joseph, & B. Palek (Eds), *Proceedings of the Fourth International Linguistics and Phonetics Conference* (pp. 575–589). Prague, Czech Republic: The Karolinium Press.

de Jong, K. J., Hao, Y., & Park, H. (2009). Evidence for featural units in the acquisition of speech production skills: Linguistic structure in foreign accent. *Journal of Phonetics, 37,* 357–373. https://doi.org/10.1016/j.wocn.2009.06.001

Eager, C. (2015). Automated voicing analysis in Praat: Statistically equivalent to manual segmentation. *The Scottish Consortium for ICPhS*, *18*, 551–585.
Flege, J. E. (1987). The production of “new” and “similar” phones in a foreign language: Evidence for the effect of equivalence classification. *Journal of Phonetics*, *15*(1), 47–65.
Flege, J. E. (1995). Second language speech learning: Theory, findings, and problems. In Winifred Strange (ed.), *Speech perception and linguistic experience in cross-language research*, (pp. 233–277). Timonium, MD: York Press.
Flege, J. E. & Eefting, W. (1987). Production and perception of English stops by native Spanish speakers. *Journal of Phonetics, 15*, 67–83.
Flege, J. E. & Hillenbrand, J. (1984). Limits on phonetic accuracy in foreign language speech production. *Journal of the Acoustical Society of America, 76*(3), 708–721. https://doi-org.ezproxy.lib.purdue.edu/10.1121/1.391256
Flege, J. E., Mackay, I., & Piske, T. (2002). Assessing bilingual dominance. *Applied Psycholinguistics, 23,* 567–598. https://doi.org/10.1017/S0142716402004046
Flege, J. E. & Port, R. (1981). Cross-language phonetic interference: Arabic to English. *Language and Speech, 24*, 125–146. https://doi.org/10.1177/002383098102400202
Flege, J. E., Yeni-Komshian, G., & Liu, S. (1999). Age constraints on second language acquisition. *Journal of Memory and Language, 41*, 78–104. https://doi.org/10.1006/jmla.1999.2638
Fricke, M., Kroll, J. F., & Dussias, P. E. (2016). Phonetic variation in bilingual speech: A lens for studying the production–comprehension link. *Journal of Memory and Language*, *89*, 110–137. https://10.1016/j.jml.2015.10.001
González López, V. (2012). Spanish and English word-initial voiceless stop production in code-switched vs. monolingual structures. *Second Language Research, 28*(2), 243–263. https://doi.org/10.1177/0267658312439821
Green, D. (1998). Mental control of the bilingual lexico-semantic system. *Langauge and Cognition, 1,* 67–81. https://doi.org/10.1017/S1366728998000133
Griffin, Z. & Bock, K. (2000). What the eyes say about speaking. *Psychological Science, 11,* 201–258. https://doi.org/10.1111/1467-9280.00255
Grosjean, F. (2008). *Studying bilinguals*. Oxford, UK: Oxford University Press.
Grosjean, F. & Miller J. L. (1994). Going in and out of languages: An example of bilingual flexibility. *Psychological Science, 5,* 201–206. https://doi.org/10.1111/j.1467-9280.1994.tb00501.x
Hammond, R. (2001). *The sounds of Spanish: Analysis and application*. Somerville, MA: Cascadilla.
Hayes, B. *Introductory Phonology*. Oxford, UK: Wiley-Blackwell.
Heike, A., Kowal, S., & O’Connell, D. (1983). The trouble with “articulatory” pauses. *Language and Speech, 26*(3), 203–214. https://doi.org/10.1177/002383098302600302
Hualde, J. I. (2005). *The sounds of Spanish.* Cambridge, UK: University Press.
Hualde, J. I., Simonet, M., &Nadeu, M. (2011) Consonant lenition and phonological recategorization. *Journal of Laboratory Phonology, 2*(2)*,* 301–329. https://doi.org/10.1515/labphon.2011.011
Jia, G., Aaronson, D. & Wu, Y. (2002). Long-term attainment of bilingual immigrants: Predictive variables and language group differences. *Applied Psycholinguistics, 23,* 599–621. https://doi.org/10.1017/S0142716402004058

Keating, P. (1990). The window model of coarticulation: Articulatory evidence. In J. Kingston & M. Beckman (Eds). Papers in laboratory phonology: Between the grammar and physics of speech. Cambridge, UK: Cambridge University Press.

Keshavarz, M. H. & Ingram, D. (2002). The early phonological development of a Farsi-English bilingual child. *International Journal of Bilingualism, 6*(3), 255–269. https://doi.org/10.1177/13670069020060030301

Khattab G. (2009). Phonetic accommodation in children's code switching. In B. Bullock & A. J. Toribio (Eds.), *The Cambridge handbook of linguistic code-switching* (pp.142–160). Cambridge, UK: Cambridge University Press.

Kühnert, B., & Nolan, F. (1999). The origin of coarticulation. In W. J. Hardcastle & N. Hewlett (Eds). *Coarticulation: Theory, data and techniques* (pp. 7–30). Cambridge, UK: Cambridge University Press.

Lakens, D. (2017). Equivalence tests: A practical primer for t tests, correlations, and meta-analyses. *Social Psychological and Personality Science*, *8*(4), 355–362. https://doi.org/10.1177/1948550617697177

Lakens, D., Scheel, A. M., & Isager, P. M. (2018). Equivalence testing for psychological research: A tutorial. *Advances in Methods and Practices in Psychological Science*, *1*(2), 259–269. https://doi.org/10.1177/2515245918770963

Lenth, R., Singmann, H., Love, J., Buerkner, P, & Herve, M. (2018). Estimated marginal means, aka least-squares means. R package version 1.3.2. https://github.com/rvlenth/emmeans

Lindblom, B. (1990). Explaining phonetic variation: A sketch of the H and H theory. In W. Hardcastle & A. Marchal (Eds.), *Speech production and speech modeling* (pp. 403–439). Amsterdam, Kluwer.

Lipski, J. (2011). Sociophonetic variation in Latin American Spanish. In M. Díaz-Campos (Ed.), *the handbook of Hispanic sociolinguistics* (pp. 72–97). Malden, MA. Blackwell Publishing.

Mack, M. (1989). Consonant and vowel perception and production: Early English-French bilinguals and English monolinguals. *Attention, Perception, & Psychophysics, 46,* 187–200. https://doi.org/10.3758/BF03204982

MacLeod, A. N., & Stoel-Gammon, C. (2005). Are bilinguals different? What VOT tells us about simultaneous bilinguals. *Journal of Multilingual Communication Disorders, 3*(2), 118–127. https://doi.org/10.1080/14769670500066313

MacSwan, J. (2013) Code-switching and grammatical theory. In T. K. Bhatia and W. C. Ritchie (Eds.), *The handbook of Bilingualism and Multilingualism* (2nd ed.) (pp. 323–350). Malden, MA: Wiley-Blackwell.

Magloire, J., & Green, K. P. (1999). A cross-language comparison of speaking rate effects on the production of voice onset time in English and Spanish. *Phonetica, 56,* 158–185. https://doi.org/10.1159/000028449

Major, R. (1987). English voiceless stop production by speakers of Brazilian Portuguese. *Journal of Phonetics, 15,* 197–202.

Marian, V., & Spivey, M. J. (2003). Competing activation in bilingual language processing: Within- and between- language competition. *Bilingualism: Language and Cognition, 6,* 97–115. https://doi.org/10.1017/S1366728903001068

Martínez Celdrán, E. (2013). Caracterización acústica de las aproximantes espirantes en español. *Estudios de Fonética Experimental, 12,* 11–35.

Muldner, K., Hoiting, L., Sanger, L., Blumenfeld, L., & Toivonen, I. (2017). The phonetics of code-switched vowels. *International Journal of Bilingualism, 19*(4), 423–443. https://doi.org/10.1177/1367006917709093

Myer-Scotton, C. (1993). *Dueling languages*. Oxford, UK: Oxford University Press.

Nathan, G. S., Anderson, W. & Budsayamongkon, B. (1987). On the acquisition of aspiration. In Georgette Ioup & Stephen Weinberger (Eds.), *Interlanguage phonology* (pp. 204–212). Rowley, MA: Newbury House.

Olson, D. J. (2012). The phonetic correlates of insertional code switching: Suprasegmental analysis and a case for hyper-articulation. *Linguistic Approaches to Bilingualism, 2*(4)*,* 439–457. https://doi.org/10.1075/lab.2.4.05ols

Olson, D. J. (2013). Bilingual language switching and selection at the phonetic level: Asymmetrical transfer in VOT production. *Journal of Phonetics, 41,* 407–420. https://doi.org/10.1016/j.wocn.2013.07.005

Olson, D. J. (2016a). The role of code-switching and language context in bilingual phonetic transfer. *Journal of the International Phonetic Association, 46*(3), 263–285. https://doi.org/10.1017/S0025100315000468

Olson, D. J. (2016b). The impact of code-switching, language context, and language dominance on suprasegmental phonetics. *International Journal of Bilingualism, 20*(4), 453–472. https://doi.org/10.1177/1367006914566204

Ortega-Llebaria, M. (2004). Interplay between phonetic and inventory constraints in the degree of spirantization of voiced stops: Comparing intervocalic /b/ and intervocalic /g/. In T. Face (Ed.), *Laboratory Approaches to Spanish Phonology* (pp. 237–253). Berlin, Germany: Mouton de Gruyter.

Pfaff, C. W., (1979). Constraints on language mixing: Intrasentential code switching and borrowing in Spanish/English. *Language, 55*(2), 291–318. https://doi.org/10.2307/412586

Piccinini, P. & Arvaniti, A. (2015). Voice onset time in Spanish-English spontaneous code-switching. *Journal of Phonetics, 52*, 121–137. ttps://doi.org/10.1016/j.wocn.2015.07.004

Poplack, S. (1980). Sometimes I'll start a sentence in Spanish *y termino en español*: Towards a typology of code switching. *Linguistics, 18,* 581–618. https://doi.org/10.1515/ling.1980.18.78.581

Poulisse, N. (1999). *Slips of the tongue: Speech errors in first and second language production*. Amsterdam: John Benjamins.

R Core Team (2013). R: A language and environment for statistical computing. R foundation for Statisical Computing, Vienna, Austria. www.R-project.org.

Romero, G. J. (1996). *Gestural organization in Spanish: An experimental study of spirantization and aspiration*. (Unpublished doctoral dissertation). University of Connecticut, Storrs, CT.

Schmidt, L. B. (2014). Contextual variation in L2 Spanish: Voicing assimilation in advanced learner speech. *Studies in Hispanic and Lusophone Linguistics*, *7*(1), 79–113. https://doi.org/10.1515/shll-2014-1159

Schmidt, L. B. & Willis, E. (2011). Systematic investigation of voicing assimilation of Spanish /s/ in Mexico City. In S. Alvord (Ed.), *Selected Proceedings of the 5th Conference on Laboratory Approaches to Romance Phonology* (pp. 1–20). Somerville, MA: Cascadilla Proceedings Project.

Schwartz, G., Balas, A., and Rojczyk, A. (2015). Phonological factors affecting L1 phonetic realization of proficient polish users of English. *Research in Language, 13*(2), 181—198. https://doi.org/10.1515/rela-2015-0014

Shea, C. E., & Curtin, S. (2011). Experience, representations and the production of second language allophones. *Second Language Research*, *27*(2), 229–250. https://doi.org/10.1177/0267658310375753

Shockey, L. (2003). *Sound patterns of spoken English*. Malden, MA: Blackwell.

Simon, E. (2010). Phonological transfer of voicing and devoicing rules: Evidence from L1 Dutch and L2 English conversational speech. *Language Sciences, 32,* 63–86. https://doi.org/10.1016/j.langsci.2008.10.001

Simonet, M. (2014). Phonetic consequences of dynamic cross-linguistic interference in proficient bilinguals. *Journal of Phonetics, 43,* 26–37. https://doi.org/10.1016/j.wocn.2014.01.004

Turk, A. (2010). Does prosodic constituency signal relative predictability/ A Smooth Signal Redundancy hypothesis. *Journal of Laboratory Phonology, 1*(2), 227–262. https://doi.org/10.1515/labphon.2010.012

Van Leussen, J.W., & Escudero, P. (2015). Learning to perceive and recognize a second language: the L2LP model revised. *Frontiers in Psychology,* 6, 1000. https://doi.org/10.3389/fpsyg.2015.01000

Volterra, V. & Taeschner, T. (1978). The acquisition and development of language by bilingual children. *Journal of Child Language, 5,* 311–326. https://doi.org/10.1017/S0305000900007492

Yavas, M. (2016). *Applied English Phonology* (3rd ed.). West Sussex, UK: Wiley and Sons.

Zampini, M. L. (1994). The role of native language transfer and task formality in the acquisition of Spanish spirantization. *Hispania, 77*, 470–481. https://doi.org/10.2307/344974

Zentella, A. C. (1997). *Growing up bilingual*. Oxford, UK: Blackwell Publishers Ltd.

Appendix A. Random Effects of Linear Mixed Effects Model: Percent Voiced $

Subject	Variance	Std. Dev.	Corr.	
Intercept	33.978	5.829		
Spanish	325.278	18.036	0.52	
Switch	27.980	5.475	-0.26	-0.32

Phoneme	Variance	Std. Dev.	Corr.
Intercept	0.717	0.846	
Spanish	2.139	1.463	-0.57
Residual	343.009	18.520	

Appendix B. Random Effects of Linear Mixed Effects Model: CV Ratio $

Subject	Variance	Std. Dev.	Corr.	
Intercept	0.0040	0.0633		
Spanish	0.0017	0.0410	-0.22	
Switch	0.0013	0.0363	-0.39	0.08

Phoneme	Variance	Std. Dev.	Corr.
Intercept	0.0002	0.0142	
Spanish	0.0006	0.0241	0.82
Residual	0.0107	0.1034	